

ALTIMETER RANGE PROCESSING ANALYSIS FOR SPACECRAFT NAVIGATION ABOUT SMALL BODIES

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The impact of using altimeter range measurements as an observation type for navigation of spacecraft about small bodies is evaluated. The altimeter range measurements can supplement or replace the standard optical landmark and Deep Space Network (DSN) radiometric tracking. Navigation of spacecraft orbiting small bodies, like asteroids, can be challenging since the a priori physical characteristics of the central body can have larger than normal uncertainties. The addition of the altimeter range data into the orbit determination problem can be used to alleviate the increased uncertainty in the dynamics of the spacecraft, due to uncertainties in the gravity model of the body. Additionally, the altimeter data can be used to speed up determination of a more accurate gravity field model. An advantage of the altimeter data is that the measurements can be taken continuously, without the sunlight restrictions of optical landmark tracking, or the station visibility restrictions of DSN tracking.

The specific cases analyzed include both orbital operations and close approaches with landing scenarios. The orbital cases include circular and elliptic orbits that include altimeter range data for altitudes below 100 km. Covariance analysis is performed to determine the accuracy of estimates of the spacecraft state and the estimates of physical parameters of the center body. The physical parameters estimated from the altimeter data include the spin state, shape, and gravity harmonics of the central body. The impact of a priori knowledge of the physical parameters, or the lack of it, on the navigation performance is also investigated. A scenario for quickly improving the knowledge of the physical parameters while providing good navigation performance during an initial orbit phase is presented. These results are applicable to a wide range of mission types to small bodies, and could be extended to include those missions targeting comets.

Simulations of possible close approaches and landing scenarios for the Near Earth Asteroid Rendezvous (NEAR) mission are used as test cases, to assess the usefulness of the altimeter range data as a navigation tool for a realistic mission scenario. The NEAR spacecraft will start orbiting the asteroid Eros in February of 2000. The close approach sequences [1] will be performed after the completion of the orbit phase [2], on January 10, 2001. Eros is shaped irregularly, with the principal semi-axes measuring roughly 16.5, 8.0, and 6.5 km. The rotation rate of Eros about the 6.5 km axis is 5.7 hours per revolution. At the time of the landing sequence, the direction from Eros to the Sun is roughly coincident with its southern angular momentum pole. Since NEAR is required to remain in

the sunlight, this limits the possible landing sites to the southern hemisphere of Eros. Landing at locations other than the pole tightens the restrictions on the timing of the de-orbit maneuvers, due to the oblong shape and relatively quick rotation rate of the asteroid. A near vertical landing at the pole allows the spacecraft to approach a steady surface, with a constant height above the center of mass. This means that the altimeter range measurements are a direct measurement of the height of the spacecraft above the landing site. Therefore, this type of scenario would allow the altimetry to make a significant contribution, in terms of navigation.

An example of this kind of scenario is outlined in Figure 1, where Eros is represented as an ellipsoid that indicates the outer envelope of the rotating body. In the figure the approximate locations of the Sun and Earth are indicated by a small star and a small circle, respectively. This sequence is made up of a close approach that is aborted at an altitude of 800 meters, followed by a landing attempt. It should be pointed out that landing is not a mission requirement for NEAR, even though it is used here as a realistic test case for the possibility.

One problem encountered in this study has been in modeling the gravity field of small non-spherical bodies at low altitudes. Normally, the gravity field would be represented using a spherical harmonic decomposition. However, this method of describing the gravity field breaks down when the radius of the spacecraft goes below the radius of a sphere that circumscribes the body. In the NEAR example, this means the gravity model breaks down when the spacecraft goes below a radius of 16.5 km (the longest Eros axis). Obviously, if we want to perform analysis of close approaches and landings at the poles, where the radius of Eros is about 6.5 km, a different representation of the gravity model needs to be used. Several options are being investigated to overcome this problem. The first method is to arbitrarily break the body into separate segments. Each of these segments can then be represented by a spherical harmonic expansion about its center of mass. This results in a gravity field that remains valid as long as the spacecraft stays outside the circumscribing sphere of each of the sections. Another method is to represent the gravity model as being due to the sum of a series of point masses, with varying magnitudes, located within the surface of the body. A third method is to use a polyhedron gravity model developed by Warner & Scheeres [3]. The problem with this method is that the partial derivatives of this gravity potential model have not been determined as yet.

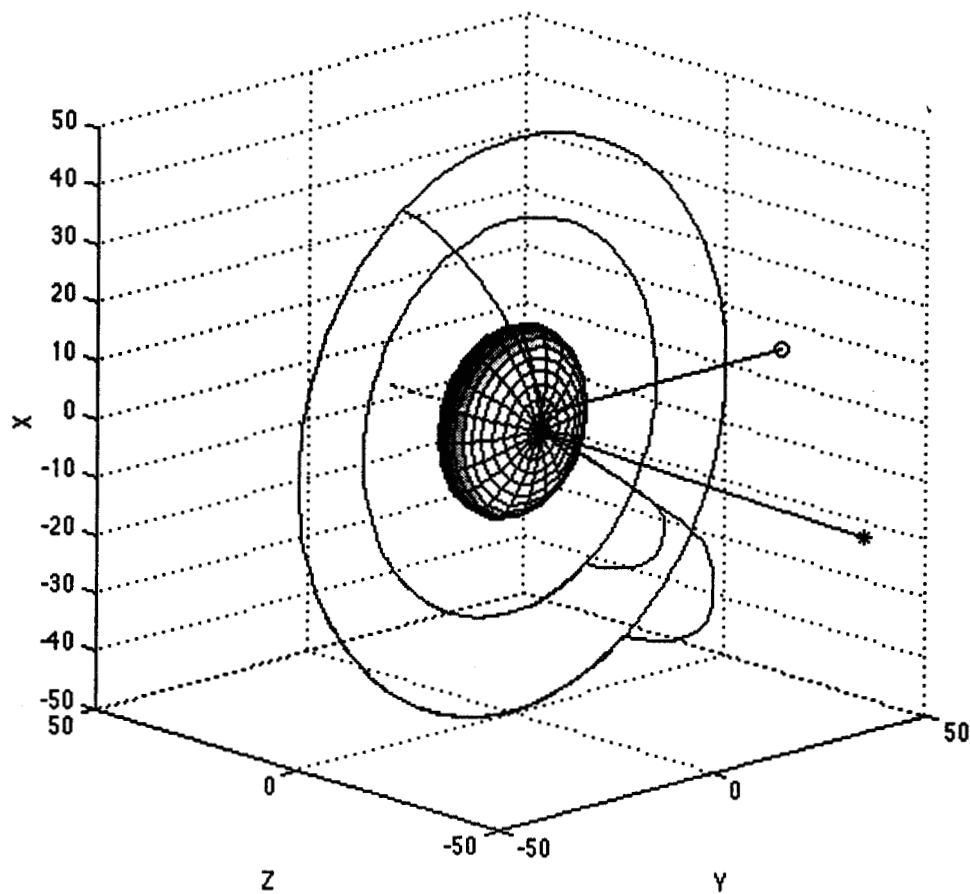


Figure 1: Close Approach followed by a landing at the South Pole of an Asteroid

References

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